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HEMATOLOGICAL ASPECTS OF HEAT STRESS IN TRAINED AND UNTRAINED M--ETC(U)
JUN 79 W VAN BEAUMONT, S UNDERKOFLER N00014-76-C-0795

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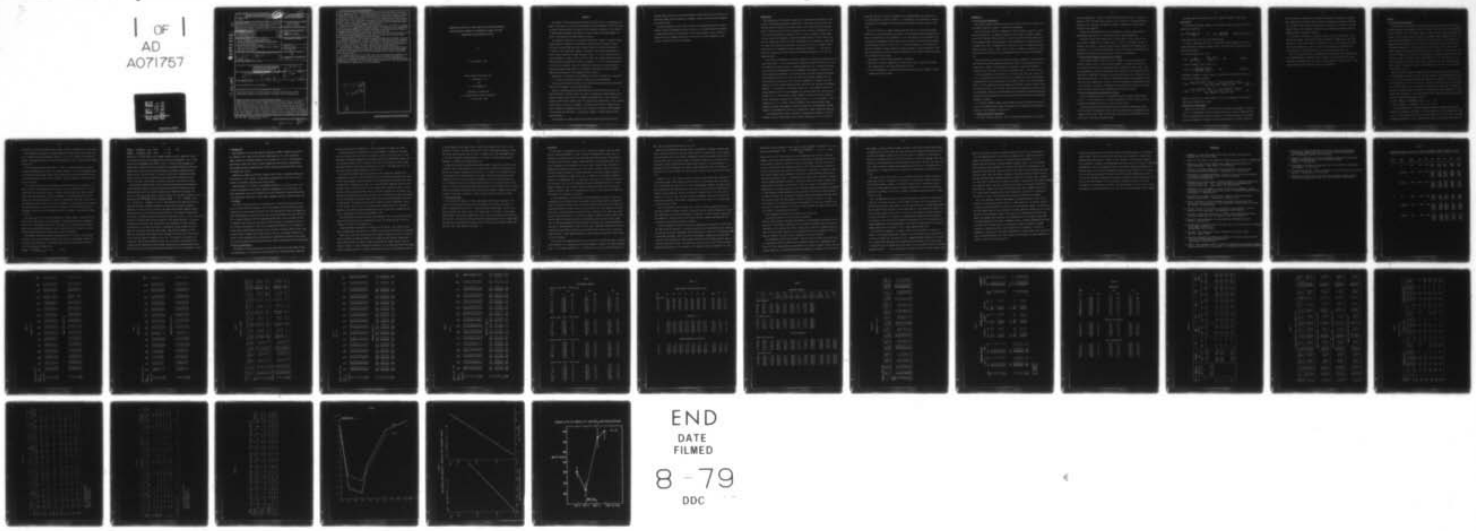

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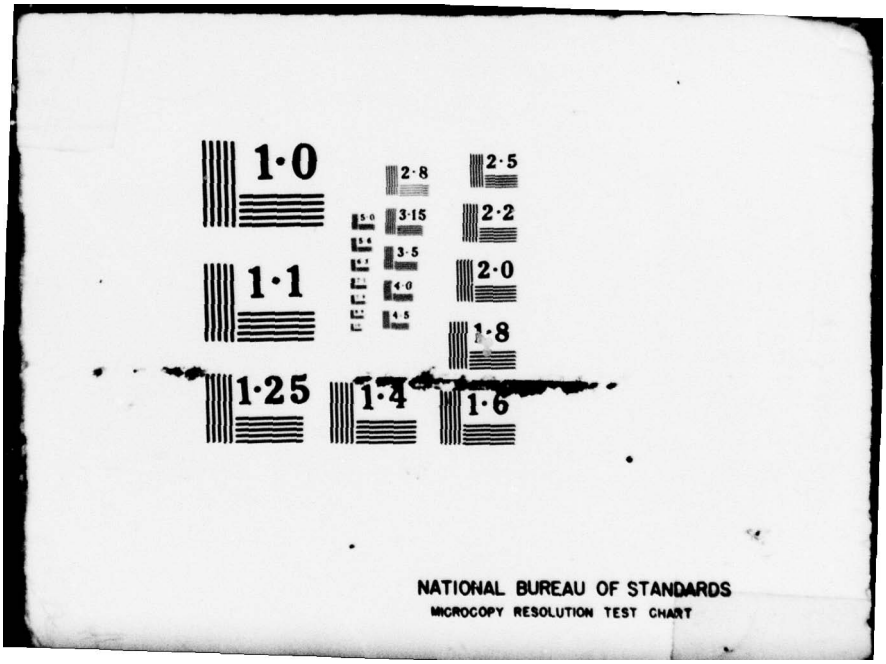
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The results of the present study indicate that with 30 min. of continued sub-maximal exercise in a cool (24°C) or warm environment (40°C) the rates of plasma volume decrease and restoration are virtually identical. At all levels of sub-maximal performance restoration of plasma volume was 80-90% complete 30 min. post-exercise and 100% complete in 60 minutes. The regression equations for calculating proportional changes in plasma volume, using changes in hematocrit and hemoglobin, indicate that the changes in mean erythrocyte volume (MCV) were small. However, based on statistical analyses, it is apparent that signif-

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Dehydration in extremely hot environments did reduce the MCV by an average value of 1.4 μ^3, which in the employed number of subjects was not significant. The antecubital venous blood became noticeably arterialized during these experiments with increments in blood pH and especially pO_2.

Physical training decreased plasma osmolarity and increased the size of the human erythrocyte. Proportionally, the shift of plasma water during maximal exercise was similar before and after training.

Acclimatization to heat induced increments in MCV which, however, were not statistically significant. In heat acclimatized subjects there was a tendency for quicker restoration of plasma volume than in non-heat acclimatized subjects after exercise in the heat. These changes are discussed with reference to concomittant changes in plasma osmolarity and plasma protein.

The mechanism of plasma volume and electrolyte shifts during exercise was examined using unilateral arm-exercise, whereby volume shifts were recorded only in the exercising limb, while blood pressures were elevated throughout the vascular space.

Of special interest was the large increase in prostaglandin precursor concentration of $PGF_{2\alpha}$ with maximal exercise. This first-ever observation is especially significant because of the possible role of prostaglandins in the coagulation processes and the frequent observation ofblood clotting immediately after exercise, especially in hot environments.

HEMATOLOGICAL ASPECTS OF HEAT STRESS IN TRAINED AND UNTRAINED MEN WITH SPECIAL EMPHASIS ON ERYTHROCYTE VOLUME, ACID-BASE BALANCE AND FLUID-ELECTROLYTE SHIFTS

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ABSTRACT

The results of the present study indicate that with 30 min. of continuous sub-maximal exercise in a cool (24°C) environment or warm environment (40°C) the rates of plasma volume decrease and restoration are vertually identical. At all levels of sub-maximal performance restoration of plasma volume was 80-90% complete in 30 min. post-exercise and 100% complete in 60 min.

The regression equation for calculating proportional changes in plasma volume, using changes in hematocrit and hemoglobin indicate that the changes in mean erythrocyte volume (MCV) were small. However, based on statistical analyses it is apparent that significant changes in the MCV do occur during sub-maximal exercise. These erythrocyte volume decrements (0.80 - 1.1 μ^3) do influence the calculated changes of plasma volume by not more than 2.5%. During exhaustive work of short duration the erythrocyte volume can expand (1 - 2 μ^3) if the acidification of the blood is extreme (< pH 7.09). While both equations for calculating proportional plasma volume changes are acceptable, the modified Strauss equation employing both hematocrit and hemoglobin has preference.

Dehydration in extremely hot environments does reduce the MCV by an average of 1.4 μ^3, which in the employed number of subjects was not significant.

The antecubital venous blood became noticeably arterialized during these experiments with increments in pH and especially pO_2.

Physical training decreased plasma osmolarity and increased the size of the human erythrocyte. Proportionally, the shift of plasma water during maximal exercise was similar before and after training. Acclimatization to heat induced increments in MCV which, however, were not statistically significant. In heat acclimatized subjects there was a tendency for quicker restoration of plasma volume than in nonheat acclimatized subjects after exercise in the heat. These changes are discussed with reference to concomittant changes in plasma osmolarity and plasma protein.

The mechanism of plasma volume and electrolyte shifts during exercise was

examined using unilateral arm exercise whereby volume shifts were recorded only in exercising limbs, with concomittant increments in mean blood pressures throughout the vascular space.

Of special interest was the large increase in prostaglandin precursor concentration of $PGF_{2\alpha}$ with maximal exercise. This first - ever observation is especially significant because of the possible role of prostaglandin in the coagulation processes and the frequent observation of the blood clotting immediately after exercise, especially in hot environments.

INTRODUCTION

The primary goal of the present study was to investigate the stability of the red cell volume during different combinations of heat and exercise stress. Conflicting results concerning the volume control of the human erythrocyte during exercise and heat stress have been reported in the literature. Meyerstein et al. (13) found no significant changes in either the mean corpuscular volume (MCV) or mean corpuscular hemoglobin concentration (MCHC) during 6 days of short term heat acclimatization at 50°C DB. These investigators also commented on unpublished results that during acute exercise in the heat they found no changes in MCV. These data are in agreement with data published by Abramson (1), who did not detect any changes in the MCV or MCHC after 30-60 min.exposure to 71°C in 2-3% dehydrated men.

In 1974 Costill published 2 consecutive papers with inconsistent results(3,4).In the earlier paper (3) the obtained data indicated a gradual decrease (up to 7%) in the MCV with either exercise or thermal dehydration and a concomitant progressive increase in plasma osmolarity (10-20 mOsm/L) resulting in a correlation of -.96 between these parameters. In the second paper the same relationship between plasma osmolarity and red cell size was found during thermal dehydration, but during muscular exercise red cell volume was independent of changes in plasma osmolarity (r=.12). During light and modest exercise in hot and warm environments Harrison (8) calculated a 1% decrease in MCV for 1.5% (4 mOsm/L) increase in plasma osmolarity, but this relationship did not hold during the recovery period. Wilkerson et al. (21) found no change in MCHC at various work levels during a 20 min. progressive exercise test (30-90 max $\dot{V}_{O_2}$) in a cool environment. In 1977 Greenleaf et al. (6) found a high correlation (.86) between plasma volume changes calculated from hematocrit (Hct) and hematocrit and hemoglobin (Hct+Hb) changes and concluded that there was no significant change in MCV with exercise.

It is apparent that concise information concerning the regulation of the individual red cell volume under various stress conditions in vivo is still not

available. Recently it has been suggested that prostaglandins can influence red cell deformability and water content (2). Consequently it was decided to evaluate concomitantly the changes in MCV and plasma prostaglandins during intensive exercise.

The actual control of plasma volume during exercise in cool and warm environments has not been established conclusively. The possibility that hydrostatic pressure is involved has to be considered (6), but few actual data are available concerning the relationship between intravascular pressures and plasma volume changes during physical exertion in man (17, 18). Since the formulas for calculating proportional changes in plasma volume were being evaluated in these experiments, there was an opportunity to obtain accurate information in this respect and intra-arterial blood pressures were recorded.

The present study was thus undertaken to determine:

1. The effect of various combinations of exercise and heat stress on the volume and configuration of the human erythrocyte in vivo.
2. To obtain information concerning the mechanisms effecting the changes in plasma volume with physical stress.

METHODOLOGY

a) Acute Exercise Experiments

Two groups of human volunteers were used to study the effects of exercise on the human erythrocyte volume in 2 different environments.

The first group of subjects consisted of 5 male volunteers (ages 22-27 yrs.) who performed 30 min. of identical separate exercise bouts in ambient temperatures of 24°C DB and 40°C DB (RH 35%) at levels of 40-75% of their maximal oxygen consumption ($\dot{V}_{O_2}$). Blood samples in these experiments were taken at 30 min. (1 sample) and 5 min. (3 samples) before exercise, 10 min. (1 sample) and 29 min. during exercise, 1 min., 2 min., 3 min., 30 min. (1 sample), and 60 min. (1 sample) post exercise. Rectal and skin temperatures were recorded by YSI thermistors.

The second group of subjects included 12 superior athletes who performed maximal exercise in 24°C DB temperature (RH 35%). Seven of these athletes were retested after 6 weeks of intense physical training, to study the influence of training on the red blood cell indices and plasma volume - electrolyte shifts.

The blood samples were analyzed for Hct, Hb, RBC, pH, pCO_2, pO_2, plasma Na, K, Cl, Ca, osmolarity, protein and lactate. The hematocrit (Hct) was determined in quadruplicate by the microhematocrit technique, with an error of measurement equal to $\pm$.25%. Quadruplicate Hb and RBC were performed on model S Coulter Counter with an accuracy of 0.4%. Plasma electrolytes were measured by standard clinical techniques; osmolarity was determined with an Advanced Instruments Osmometer; plasma protein was analyzed by the Biuret method and lactate with the Boehringer enzymatic procedure.

To evaluate changes in $PGF_{2\alpha}$ during maximal exercise the stable major metabolite 13,14-dihydro-15-keto $PGF_{2\alpha}$ was analyzed in the obtained blood samples, according to the technique of Levine (10).

b) Thermal Dehydration Experiments

Four male volunteer subjects - three of whom participated also in the acute

exercise experiments - rested in a semireclining position for 2½ - 3 hours in a climate of 58°C, 27 mm Hg vapor pressure, until a level of 2.5% dehydration was obtained. At no time were the subjects allowed to change their body position during the heat exposure.

Internal and skin temperatures were continuously recorded, while metabolic measurements were made at 15, 60, 90 and 120 min. during dehydration.

Antecubital venous blood samples (10 cc) were taken at 5 min. prior to the heat stress (3 samples from 1 venepuncture), at 25 min. (2 samples), 60 min. (2 samples) and 120 min. (3 samples) during the heat exposure and 20 minutes after returning to a cool (25°C DB) environment. Except for lactate (not measured) all samples were analyzed as was done during the exercise experiments.

c) Plasma Volume Changes and Hydrostatic Pressures

Six volunteer subjects (mean age 33 yrs., weight 78.4 Kg) performed a progressive exercise test on a motor driven treadmill. A catheter was placed in the brachial artery with the recording pressure transducer at heart level. Resting measurements of HR, BP and hematocrit were obtained in the standing position. Each subject performed 5 different workloads consecutively until exhaustion. Each workload was maintained for 3 minutes, during which period blood pressures, heart rates and blood samples were collected. The blood samples were immediately analyzed for hematocrit readings in quadruplicate. One post-exercise series of measurements was made 4 minutes after termination of the exercise stress.

d) Heat Acclimatization and Erythrocyte Volume

Four male subjects were heat acclimatized during the winter months through daily 3½ - 4 hour exposures to an ambient temperature of 40°C, 30% RH while performing intermittently exercise at a level of 50% max $\dot{V}_{O_2}$.

Resting and exercise blood samples were taken before and immediately after the 10 day heat acclimatization period. Heat acclimatization was assessed by the changes in heart rate, sweat rate and body temperatures. Blood samples were analyzed in the previously described manner.

Informed consent was obtained from all volunteer subjects in this study.

Calculations

To evaluate the possible changes in erythrocyte volume two mean red cell indices were calculated:

$$MCV = \frac{(Hct \times 10) \times .96}{RBC} \quad \text{and} \quad MCHC = \frac{100 \times Hb}{Hct \times .96}$$

where the factor .96 corrects the hematocrit value for trapped plasma.

In order to determine the effect of erythrocyte volume changes on the calculated proportional changes in plasma volume, the latter were calculated by two different equations:

1. from the changes in Hct (19):

$$\%\Delta PV = \frac{100}{100 - Hct_{pr}} \times \frac{Hct_{pr} - Hct_{po}}{Hct_{po}} \times 100 \qquad \text{Equation 1}$$

2. from the changes in Hct and Hb (6):

$$\%\Delta PV = 100 \left[\frac{Hb_{pr}(100 - Hct_{po})}{Hb_{po}(100 - Hct_{pr})} \right] - 100 \qquad \text{Equation 2}$$

Consequently changes in plasma content of electrolytes and proteins were calculated by two different methods:

1. $$\%\Delta Co = \frac{Cn_{po} \left[Hct_{pr}(100 - Hct_{po}) \right] - Cn_{pr} \left[Hct_{po}(100 - Hct_{pr}) \right]}{Cn_{pr} \left[Hct_{po}(100 - Hct_{pr}) \right] / 100}$$ Eq. 3 (ref. 6)

2. $$\%\Delta Co = \frac{Cn_{po} \left[Hb_{pr}(100 - Hct_{po}) \right] - Cn_{pr} \left[Hb_{po}(100 - Hct_{pr}) \right]}{Cn_{pr} \left[Hb_{po}(100 - Hct_{pr}) \right] / 100}$$ Eq. 4

where pr = minus 5 min. resting sample, and po = the subsequent blood samples with exercise and/or heat stress.

Reliability of Measurements:

Because the calculation of the red blood cell indices is dependent on the accuracy of 2 measurements, special attention was paid to factors influencing hematocrit, hemoglobin and red blood cell count. Of primary interest was the possibility that exposure to ambient air with its different pO_2 and pCO_2 compared to

blood could affect the hematocrit and RBC determinations. Hematocrit readings were compared after normal standard laboratory technique and anaerobic handling of fresh blood. These comparisons indicated no significant difference in the obtained results, and consequently hematocrit was thereafter determined with the standard aerobic laboratory procedure.

To evaluate the influence of blood gas tension (pO_2) on the Coulter counter analyses the freshly drawn venous blood was analyzed a) immediately (and anaerobically); b) after a few minutes of exposure to air; c) after shaking and equilibration with ambient pO_2. Also in this case no significant differences were found between the 3 determinations on the same blood sample (Table 1).

Since in some publications only Hemoglobin concentrations were determined with the cyanmethemoglobin technique, 30 blood samples were analyzed for Hb by this technique and compared with the Coulter counter analyses. Twenty-nine out of the thirty analyses gave identical values for both methods.

RESULTS

a) Acute Exercise Experiments

In the range of the presently studied work performances (40-75% max $\dot{V}_{O2}$), hemoconcentration was always apparent shortly (10 min.) after the start of the muscular activity (Tables 2, 3). The largest change in plasma volume occured during the first 10 min. of the exercise phase, whereafter the plasma volume remained virtually constant during the remainder of the 30 min. work periods (Table 4). The changes in plasma volume during this period of exercise were affected very little by the environmental temperature. After termination of the physical activity there was a faster increase of plasma volume during the first 3 minutes of recovery in the cool ($24^{o}C$) environment, but thereafter the restoration of plasma volume occured at the same rate in the cool and hot ($40^{o}C$) environments (Fig. 1). After 30 min. of recovery restoration of plasma volume was 87% complete in the cool environment and 75% in the hot climate and virtually 100% complete after 60 min. in both environments (Table 4, Fig. 1).

These calculated changes in plasma volume are influenced by the volume control of the individual erythrocyte. While the mean changes in the MCV where small (0.8-1.1 μ^3), statistical analysis indicated significant decrements ($P<.05$) in the red cell volumes near the end of the 30 min. exercise period and the first few minutes of recovery (Tables 5, 6). Accordingly the proportional reductions in plasma volume were calculated using both hematocrit and hemoglobin values (Equation 2). Comparing the two methods of calculating proportional changes in plasma volume resulted in the following regression equations:

in $24^{o}C$: $\%\Delta PV_{Hct} = 0.99(\%\Delta PV_{Hct + Hb}) + .72$; $r = .98$

in $40^{o}C$: $\%\Delta PV_{Hct} = 0.92(\%\Delta PV_{Hct + Hb}) - .05$; $r = .97$

It was established by the means comparisons method of Newman-Keuls, that although the regression coefficient at $24^{o}C$ was identical with the theoretical value of $\beta = 1$, that obtained at $39^{o}C$ was reliably smaller ($F = 4.57$; $P<.05$). From these regression equations it can be determined that under the described conditions the

difference in calculated plasma volume changes by these 2 methods will not exceed 2%.

The concomitant increments in plasma osmolarity during exercise were on the average 7-8 mOsm/L in both environments (Tables 5, 6). The total sweat loss during the 90 min. experimental periods were 650 and 1200 grams in the cool and hot environments respectively.

All the measured plasma constituents - except K - showed decreases in content during these submaximal exercises. The plasma contents of Na and Cl diminished nearly isotonically with plasma volume, while plasma protein content decreased only by 1.6-2.8% and plasma calcium by 2-6%. Plasma K content increased by 7-9% during the exercise periods.

The acid-base balance in the antecubital venous blood was only influenced to a minor extent by the submaximal leg exercises or the environment (Table 7). The pH during exercise and recovery showed a slight rise [Non Significant (NS)] at workloads less than 55% max $\dot{V}_{O_2}$ in both environments. At workloads greater than 55% max $\dot{V}_{O_2}$ the pH decreased slightly in the cool environment (less than .05 pH units) and remained virtually stable in the hot environment. The antecubital pCO_2 remained unaltered during the low exercise loads but decreased by 8-9 mm Hg with heavier submaximal exercise in both environments ($P<.05$), returning to pre-exercise levels in 30 min.

The venous pO_2 in the resting arm showed the largest changes, increasing 10-14 mm Hg during light work in both environments, 20 mm Hg during heavier submaximal work in cool environments and 9 mm Hg in the heat. After light exercise periods there was an additional significant rise in venous pO_2 (10-12 mm Hg) for several minutes before returning to pre-exercise levels in 30 minutes.

With maximal exercise the plasma volume decreased 15.7-15.9% in the untrained athletes, 16.7% in the trained athletes and 17.5% in the non-athletes (Table 14). Evaluating both methods for calculating plasma volumes the regression equations for these groups were respectively:

$$\%\Delta PV_{Hct} = 1.05(\%\Delta PV_{Hct + Hb}) + .22 \; ; \qquad r = .90$$

$\%\Delta PV_{Hct} = .90(\%\Delta PV_{Hct + Hb}) - 0.90$; $r = .94$ and

$\%\Delta PV_{Hct} = .86(\%\Delta PV_{Hct + Hb}) - 1.80$; $r = .96$

Restoration of plasma volume after maximal exercise was not complete in 25 min. of recovery, but the rate of plasma water return was approximately 1½x as fast as that after submaximal work (Table 4, Fig. 1). Plasma content changes were larger after maximal exertion but followed the same general pattern as with submaximal work, except for much larger decrements (20-22%) in plasma potassium during the 2nd, 3rd and 4th min. of recovery. MCV showed a significant ($P<.05$) volume expansion in the non-athletes and untrained athletes during the first 3 min. of recovery. After 30 min. the MCV was restored to pre-exercise values.

The concomitant measurements of intra arterial blood pressures and hematocrit in six different subjects revealed a progressive and linear increment in both hemoconcentration and mean arterial blood pressure (MAP) with increasing work-stress as indicated by the oxygen consumption ($\dot{V}_{O_2}$). The regression equations (Fig.2) between Hct, MAP ($\frac{SBP + DBP}{2}$ mm Hg) and $\dot{V}_{O_2}$(ml/min/Kg) : $Hct = .108(MAP) + 29.5$ ($r = .94$) and $Hct = .102(\dot{V}_{O_2}) + 41.6$ ($r = .98$) demonstrate the high interrelationships between these parameters during the exercise period. However during the immediate (+ 3 min.) period of recovery, the mean blood pressure dropped sharply, while hematocrit levels remained elevated (Table 8). In 2 subjects who performed 1.5-2.0 min. unilateral isometric and isotonic right hand exercise - which evoked substantial rises of 20-25 mm Hg mean blood pressure in the resting left arm - no hemoconcentration was observed in the control arm, with significant ($P<.05$) increments of hematocrit in the right arm (Table 9). Significant ($P<.05$) changes were also observed in blood pH, pCO_2, pO_2, plasma [Na], [K], [Ca] and osmolarity in the right arm antecubital venous blood, with no changes in the left side. Restoration to pre-exercise levels was complete after 2 min. of recovery in electrolyte concentrations. MCV decreased during the first min. of exercise concomitantly with a highly ($P<.05$) significant rise in plasma osmolarity but increased significantly ($P<.05$) during the recovery period when blood acidity was still considerably elevated.

b) Dehydration

Upon exposure to a very high ambient temperature (58°C, 30% RH) during absolute immobile rest, there was an initial hemodilution of 1%, with concomitant small elevations in plasma osmolarity and in plasma Na, K, Cl, Ca concentrations and contents (Table 10). None of these changes were statistically significant, only plasma protein concentration and content decreased during the first 25 min. of intense heat stress.

Significant changes ($P<.05$) were observed after 60 min. in plasma calcium concentration and after 135 min. in the plasma concentrations of Na, Cl, Ca and K, as well as in plasma osmolarity and total protein.

MCV decreased 1.4 μ^3 (Table 11) and MCHC increased 1.1 percentage units after 2 hours of dehydration and neither change was significant at the .05 level. In these experiments there were significant ($P<.05$) increments in venous pH and pO_2, with significant decreases in venous pCO_2 throughout the heat exposure (Table 12).

c) Training

Six weeks of intense physical training by the 7 athletes increased their max $\dot{V}_{O_2}$ by 4.8% ($P<.05$) but decreased the H^+ concentration ($P<.05$) and blood lactate concentration with maximal work (Table 13). The training did reduce the hematocrit (NS), the hemoglobin concentration ($P<.05$) and the red blood cell count ($P<.05$) in the 7 retested athletes (Table 13,14)Simultaneously there was an increase ($P<.05$) in the MCV, with concomitant decreases ($P<.05$) in plasma concentration of Na, Cl, Ca, protein and osmolarity. There was no significant difference in the shift of plasma water during maximal exertion before and after training. Also the ionic and protein content changes with maximal exercise were not noticeably different as a result of the training period. Training had no significant influence on the blood gas tension changes in the antecubital venous blood with maximal exercise (Table 15).

d) Heat Acclimatization

Ten days of 4 hours heat exposure in this study evoked the usual signs of heat acclimatization i.e. decreases in exercise heart rate (-10 beats/min.), decrease

in post-exercise rectal temperature (-.4°C) and increase in sweat rate (+10%).

In addition there were significant ($P<.05$) decrements in hematocrit and hemoglobin concentrations; from these last values it could be calculated (eq. 2) that the plasma volume had expanded by 8.4% during the heat acclimatization period. The 4.2% decrease in RBC could be accounted for by the 4.4% increase in blood volume. The plasma protein concentration decreased from 7.48 to 7.20 gram% (Table 16), but the total protein content increased by 4.3% (eq. 4).

Both the MCV and MCHC indicated increments in the erythrocyte volume with acclimatization to heat, but the differences were not statistically significant. None of the other parameters measured (Table 16) were significantly different after heat acclimatization. Resting in the heat for 1 hour initiated comparable levels of hemodilution before (+4.9%) and after (+6.1%) adaptation to high heat stress. The erythrocyte volume remained constant during 1 hour heat exposure but the plasma K concentration increased ($P<.05$) before and after heat acclimatization, while the plasma protein concentration decreased significantly only during the experiment after heat acclimatization. The plasma protein content remained virtually unaltered (-.8% to -1.4%Δ) during 1 hour of rest in the intense heat. During one hour of exercise at 50% max $\dot{V}O_2$, the MCV decreased significantly ($P<.05$) in the heat acclimatized subjects, simultaneously with an increase MCHC ($P<.05$).

The proportional decreases in plasma volume during 1 hour of exercise were 13.0% before and 16.8% after heat acclimatization, while the plasma protein content decreased by 2.9% and 1.6% respectively.

Plasma osmolarity increased by 9.8 mOsm/L (+3.3%) during 1 hour exercise after heat acclimatization compared with 4.7 mOsm/L (+1.6%) before the daily heat exposures.

Thirty min. after the exercise period the plasma volume had deficits of 4.4% and 6.0% in non-heat acclimatized (N-HA) and acclimatized (HA) subjects respectively, which indicated that the rate of volume restoration was slightly faster (8.6% vs 10.6% in 30 min.) in the acclimatized individuals. In the same time period the plasma protein content was still 3.1% below the pre-exercise value in N-HA subjects, while

in the HA subjects the plasma protein content had increased from -1.6% to +.8% during the recovery. The same trend can be noticed in the plasma osmolarity, where the 30 min. post-exercise value was only 1.5 mOsm/L lower than the highest value at the end of exercise in N-HA subjects, in contrast to the HA subjects where a decrease of 5 mOsm/L was recorded (Table 16).

During the recovery period the MCV and MCHC showed a progressive return to pre-exercise volume of the erythrocyte in HA individuals, however the erythrocyte volume was not restored completely in the 30 min. of recovery. The influence of heat acclimatization on acid-base balance was minimal. Blood pH increased during the transient from the cool to the warm environment by virtually the same values in the 2 conditions. Venous pO_2 increased during the heat - rest period and the first 5 min. of exercise recovery and maintained thereafter levels between 65 and 75 mm Hg. Venous pCO_2 gradually decreased during resting heat exposure, slightly more during exercise in the heat, followed by a small increase during the recovery period.

e) Prostaglandin $PGF_{2\alpha}$

The concentration changes of $PGF_{2\alpha}$ with maximal exercise were assessed on the basis of the stable major metabolite 13,14-dihydro-15-keto $PGF_{2\alpha}$. The data in Table 18 represent the values of 12 athletes obtained during their max $\dot{V}_{O_2}$ test before training. The results show a very significant rise ($P<.001$) in the plasma prostaglandin concentration immediately (1 min.) after the maximal exercise stress. After 25 min. of recovery the $PGF_{2\alpha}$ metabolite concentration was still significantly ($P<.001$) above the resting pre-exercise level and was actually slightly higher (NS) than the 1 min. post-exercise level(Fig. 3).

DISCUSSION

In the range of the employed work rates a decrease in plasma volume was observed early in each experiment. In none of these 26 experiments was there later an indication of plasma volume restoration during the 30 min exercise. This observation agrees with the near constant plasma osmolarity values measured after the initial increment on the transition from rest to work. Plasma volume decreased by insignificant amounts during the rest of the 30 min. exercise period. The calculated proportional decrements in plasma volume were consistantly slightly smaller on the basis of hematocrit changes alone (eq. 1) compared to the combined changes of hematocrit and hemoglobin (eq. 2). This may be the result of the small but consistant decrease in the red cell volume (MCV) during the submaximal exercise in either ambient temperature. The observed difference between the methods of calculating changes in plasma volume is in agreement with Costill's data, however the observed discrepancy will normally not exceed 2%.

In these experiments the antecubital venous pH remained virtually constant and consequently the acid-base balance was stable. Since plasma osmolarity invariably showed a noticeable increase, the forces effecting the erythrocyte in vivo were unbalanced, resulting in osmotic water loss from the red cell. The changes in the MCV were small and became apparent and statistically significant only after many observations and determinations in a sufficient number of subjects. Using the MCV rather than the MCHC to evaluate erythrocyte volume enhanced the accuracy since a small error in the Hb measurement will proportionally influence the calculated MCHC more than similar determinations of RBC will effect MCV. Individual differences were noticeable with some subjects having red cells which under certain stress conditions showed definite volume changes, whereas in other subjects erythrocyte volume remained fairly constant.

Our results from submaximal exercise in cool and hot environments agree in general with Harrison's ([8]) observations in warm environments. However, the slightly larger increments in plasma osmolarity (2.3 - 3.0%) did not result in greater decreases in

MCV (-1%) than reported by Harrison et al.(8).

Costill's conclusion that changes in MCV are unrelated to changes in plasma osmolarity results from the fact that the volume control of erythrocytes is also related to the acid-base state of the blood. Consequently at work rates greater than 75%, or when pH levels fall below 7.30, changes in acid-base balance start to effect the intracellular osmotic equilibrium and plasma osmotic pressure is counterbalanced. In agreement with this mechanism, the present study demonstrates that acid swelling of erythrocytes can occur during very heavy muscular exercise with blood pH levels below 7.10.

Greenleaf et al. (6) reported a high correlation (.86) between the 2 methods of calculating plasma volume changes during exercise: in the present study the correlation coefficients were .98 and .97 in the two environments. However, the high correlation between the two methods does not mean that the actual absolute values are necessarily nearly identical, and the conclusion by Greenleaf et al. (6) that either method is accurate is only true when the MCV is unchanged. This can occur with very high intense muscular efforts when counterbalancing forces result in a constant MCV as reported earlier.(20)

Since fluctuations of MCV can thus occur, Costill correctly suggested that proportional changes in plasma volume be calculated from the combined changes in Hct and Hb. Consequently the derived relationship in equation 2 is more generally applicable than equation 1, which in most cases will provide an acceptable approximation but can only be accurate when the MCV is constant.

Precise evaluation of plasma constituent movements should therefore be done with the application of equation 4. The results based on this relationship clearly indicate that during the 30 min. submaximal exercise periods the contents of all measured plasma constituents decreased, except potassium. Environmental temperature and thus sweat rate had little influence on these plasma constituent shifts during the half hour of continuous muscular activity. The observation that calcium is lost from the vascular system during exercise is in contrast to the findings by Keys and Adelson (9), who

stated that neither ionized or total calcium may be diffusable. Greenleaf et al. (6) using the relationship $Ca^{++} = \frac{[6.25(Ca_t) - 0.375(Prot_t)]}{Prot_t} + 6.25$ (6) found a larger shift of Ca^{++} than plasma water during submaximal exercise and a hypotonic ionized calcium shift during maximal exercise. Employing the same equation our data also indicate a hypotonic ionized Ca^{++} shift during maximal exercise, but only an isotonic $[Ca_i]^{++}$ shift with submaximal exercise. The recovery pattern of plasma potassium concentration after exertion is different for submaximal as compared to maximal exercise. While after submaximal exercise the plasma potassium concentration and content gradually return to the pre-exercise levels, upon cessation of maximal exercise plasma potassium decreases to values well below the original plasma concentration before returning to pre-exercise values. As a result of the large shift of plasma water, the plasma potassium content invariably shows proportionally an extremely large negative content immediately post-exercise. The reason for this difference is likely related to the variation in acid-base balance with maximal exercise, where the increase in $[H^+]$ and pCO_2 appears to have an influence on the Na - K pump. An increase in H^+ concentration enhances the movement of K ions out of and Na^+ ions into the cell. Upon cessation of exercise 2 factors enhance the sharp decline in extra-cellular K concentration and content:

1) The immediate decrease in $[H^+]$ and pCO_2 (see table 14).

2) The extra-cellular to intra-cellular K gradient.

From the extra-cellular acid-base measurements of the submaximal exercises in this study (40 - 75% max $\dot{V}_{O_2}$) it appears that H^+ increase is minimal, aided by efficient buffering at the cellular level. Thus in this type of exercise a sudden decrease in extra-cellular K after exercise is not expected because 1) the changes in $[H^+]$ and pCO_2 are insignificant and 2) the K^+ gradient is far less extensive.

The mechanism by which fluid-transfer from the vascular system occurs has been a controversial topic for several years. Recently Lundvall (11) claimed that more than 75% of the transcapillary fluid-transfer is a result of osmotic forces, the remainder being due to increased transcapillary hydrostatic pressure. Our data do in-

deed suggest a high correlation between increase in mean blood pressure and decrease in plasma volume. The fact that the fluid-transfer can be evoked unilaterally by one-arm exercise suggests strongly that the local forces of osmosis and vasodilatation must work in synchrony with the filtration pressure to evoke the response, since the increase in blood pressure was obviously present bilaterally. The fact that there was also a high correlation between hemoconcentration and work rate, illustrates the interdependency of plasma water shift, increase in blood pressure and intensity of exertion.

The higher rate of fluid return to the vascular system after maximal exercise is undoubtedly related to hyperemia in the muscles, restoring the cellular osmolarity and acid-base balance rapidly to pre-exercise values, with a concomittant slower decline in plasma osmotic pressure and rapid normalization of systemic hydrostatic pressure. The evidence for the aid of lymphatic drainage during this period is hypothetical in man.

The 2.5% dehydration evoked by resting heat exposure resulted in a 1.6% decrease in MCV and an average increase of 2.8% in MCHC. The reason for this discrepancy is probably more related to the greater accuracy and sensitivity of the RBC measurements and calculated MCV values than to actual differences in the erythrocyte indices. In any case these changes in the red cell volume are much smaller than those reported by Costill and Fink (3) in subjects 2% dehydrated by intermittent heat exposure, but are more in line with results obtained by Harrison et al. (8) in subjects exercising submaximally in warm environments. As a result the differences in calculated plasma volume shifts by equation 1 and 2 seldom extend beyond 2.5%.

On the basis of equation 4, it appears that all ions decreased in content as a result of the resting intense heat exposure, but the temporal pattern was different for each ion (Table 10). The small effect of augmented plasma osmolarity on the red cell volume may be influenced by the apparent arterialization of the venous blood, as indicated by the increased pH and pO_2 levels in the antecubital blood. It has been suggested earlier , that erythrocytes in arterial blood are slightly smaller than

those in venous blood; however conclusive evidence for this is not overwhelming.

The most apparent effect of the 6 weeks training in the 7 athletes was the decrease in concentration of virtually all measured blood parameters. If it is assumed that the red blood cell mass remained constant, than it can be calculated that the plasma volume expanded by 5.5% which would explain the decrements in the constituent concentrations. This could also be the basis for the measured significant increase in MCV, since the chronic lowering of the plasma osmolarity would decrease the extracellular osmotic pressure around the erythrocyte, allowing them to increase in volume. That in this group of athletes the shifts in plasma water with maximal exercise were identical before and after training may be related to the modest elevations in their max $\dot{V}O_2$. However the plasma volume changes with short maximal exercise were of the same order of magnitude and large fluctuations resulting from training are not likely to occur if the body mass and composition remain fairly constant.

One of the important adaptative mechanisms of repeated exposure to heat is the expansion of plasma volume, which leads to a lower hematocrit and reduced viscosity of the blood,thus diminishing the strain on the cardiovascular system. In addition it now also appears that the large increment in plasma osmolarity during work in the heat after heat accclimatization reduces the volume of the human erythrocyte more than before the repeated heat exposures, thus compensating for the slightly larger MCV in resting subjects who have been acclimated to heat. Prolonged submaximal work does not effect the acid-base balance of blood and the larger increments in plasma osmolarity - possibly related to the increased rate of sweating - can thus act unopposed on the red cell. The faster restauration of plasma volume after exercise in heat acclimatized subjects can be the result of the quicker and larger expansion of protein content after the work period.

Of special interest was the very large increase of the PGF precursor 13,14 dihydro-15-keto $PGF_{2\alpha}$. This is the first time that such large increments in these prostaglandins have been reported ; however in 1972 Greaves et al(5) reported a similar but non-specific increment in prostaglandins with exercise and very recently significant augmentation of PGE with submaximal exercise was found by Nowak and Wennmalm (16). The particular role of these prostaglandins during muscular exercise is not defined but the various prostaglandins influence bloodflow through vasodilation and vasoconstriction (PGE,PGF), coagulation and platelet aggregation (PGI,thromboxane) (14). The fact that the increase in PGF concentration remained allevated for at least 25 minutes of recovery may be related to the normal function of any or all of these mechanisms, but these possibilities will have to be resolved through further research.

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TABLE 1

COMPARISON OF RBC, Hct, Hb, MCV and MCHC AT DIFFERENT BLOODGAS TENSIONS IN VITRO

Sample	Time	pCO_2	pO_2	pH	Hct	RBC	Hb	MCV	MCHC
1	0	54.4	15.0	7.30	45.1	5.62	16.[illegible]	80.2	36.6
					45.1	5.65	16.4	79.8	36.4
	+ 20 min	53.6	36.9	7.30	45.0	5.59	16.5	80.5	36.7
					45.0	5.63	16.7	80.0	36.6
					45.1	5.60	16.5	80.5	36.6
					45.1	5.66	16.5	79.7	36.6
	+ 60 min	55.0	144.0	7.31	45.0	5.61	16.5	80.2	36.7
					44.9	5.63	16.6	79.7	36.9
					45.0	5.62	16.5	80.0	36.7
					45.0	5.67	16.6	79.7	36.9
2	0	56.8	17.3	7.28	45.4	5.72	16.3	79.2	36.0
					45.3	5.70	16.4	79.4	36.2
					45.3	5.69	16.4	79.6	36.2
	+ 20 min	54.2	38.5	7.28	45.2	5.70	16.5	79.3	36.5
					45.2	5.69	16.7	79.4	36.9
					45.3	5.73	16.4	79.1	36.2
					45.3	5.72	16.4	79.2	36.2
	+ 60 min	51.1	145.0	7.30	45.2	5.71	16.5	79.1	36.5
					45.2	5.70	16.5	79.3	36.5
					45.2	5.69	16.4	79.4	36.3
					45.2	5.70	16.4	79.3	36.3

TABLE 2

HEMATOCRIT (%)

Ambient Temp. 24°C

Subj.	TI	TI	RE	RE	CL	CL	CL	FU	FU	FU	RO	RO	RO	$\bar{X}$	SD	±SE
% Max $\dot{V}_{O_2}$	57%	65%	41%	60%	40%	55%	58%	44%	57%	74%	52%	60%	75%	56%	10	3
Time (min.)																
- 5	44.4	44.6	37.4	36.7	36.6	36.6	36.6	41.0	40.4	41.4	35.9	37.6	35.6	38.8	3.2	.9
10	45.4	47.5	38.6	39.1	38.0	39.2	39.2	42.3	44.7	45.3	38.4	40.2	39.3	41.3	3.3	.9
29	45.3	47.9	37.9	40.2	38.5	39.0	39.6	42.8	44.0	46.5	37.9	40.6	39.3	41.5	3.4	.9
+ 1	44.8	47.7	38.0	40.1	38.1	38.8	39.1	42.6	44.9	46.3	38.2	40.3	39.3	41.4	3.4	.9
+ 2	45.2	47.1	37.8	39.8	37.7	39.1	38.6	42.6	44.4	45.8	36.9	40.0		41.3	3.6	1.0
+ 3	44.5	46.5	37.7	39.5	37.5	38.2	39.1	42.3	43.6	45.4	36.9	39.2	38.2	40.7	3.3	.9
+30	42.8	43.2	36.8	36.1	37.1	37.0	37.4	41.9	42.0	42.1	36.7	38.4	36.6	39.1	2.8	.8
+60	43.5	43.7	36.7	36.0	36.7	37.4	36.6	40.9	40.1	40.4	35.8	37.2	35.9	38.5	2.8	.8

HEMOGLOBIN (gr/100 ml)

- 5	18.0	17.6	14.4	13.9	14.1	13.8	14.3	16.7	16.6	16.6	14.0	14.5	14.0	15.3	1.6	.4
10	18.6	19.0	15.1	15.1	14.9	15.1	15.4	17.3	18.1	18.3	15.0	16.1	15.6	16.4	1.6	.4
29	18.6	19.1	15.0	15.6	15.1	15.0	15.7	17.8	18.4	19.0	14.9	16.3	15.7	16.6	1.7	.5
+ 1	18.5	18.9	14.9	15.4	14.9	14.8	15.4	17.6	18.5	18.5	14.7	16.1	15.6	16.4	1.7	.5
+ 2	18.5	18.8	14.8	15.3	14.9	15.0	15.3	17.5	18.2	18.4	14.5	15.8		16.4	1.7	.5
+ 3	18.2	18.5	14.7	15.1	14.9	14.6	15.4	17.4	18.0	18.3	14.5	15.4	15.1	16.2	1.6	.4
+30	17.4	17.5	14.3	13.8	14.6	14.2	14.6	17.1	17.0	17.0	14.4	15.1	14.3	15.5	1.4	.4
+60	17.8	17.6	14.2	13.8	14.3	14.2	14.4	16.6	16.3	16.2	13.9	14.6	14.0	15.2	1.5	.4

TABLE 3

HEMATOCRIT (%)

Ambient Temp. 40°C

Subj.	TI	TI	RE	RE	CL	CL	CL	FU	FU	FU	RO	RO	RO	$\bar{X}$	SD	±SE
% Max $\dot{V}_{O2}$	53%	56%	41%	60%	41%	55%	60%	38%	62%	74%	52%	60%	73%	56	10	3
Time (min.)																
- 5	44.7	43.0	35.1	35.7	37.9	37.9	36.6	41.2	38.5	41.2	38.5	37.8	39.1	39.0	2.8	.8
10	46.8	44.6	36.7	37.7	39.4	39.5	39.1	42.0	41.0	45.2	40.2	40.2	41.2	41.0	2.9	.8
29	46.6	44.1	37.4	38.3	40.0	40.1	39.3	42.1	42.1	46.3	40.5	40.2	42.0	41.4	2.8	.8
+ 1	46.1	44.0	37.0	38.3	39.5	39.5	39.1	41.7	42.0	46.8	40.2	40.1	41.8	41.2	2.9	.8
+ 2	46.3	44.0	37.4	38.7	39.3	39.6	39.1	41.9	41.7	44.6	40.2	40.0	41.8	41.1	2.6	.7
+ 3		44.0	37.5	38.2	39.3	39.5	38.6	41.9	41.7	44.0	40.2	40.0	41.0	40.5	2.1	.6
+30	43.9	42.7	35.9	36.4	39.1	38.6		41.4	40.4	39.3	39.1	38.3	39.6	39.6	2.3	.7
+60					38.0	38.0	36.6	40.6	39.3	38.7	39.1	38.2	39.3	38.6	1.1	.4

HEMOGLOBIN (gr/100 ml)

- 5	18.1	17.4	13.6	13.4	14.8	14.6	14.2	16.9	15.6	16.8	15.2	15.0	15.6	15.5	1.5	.4
10	19.2	18.0	14.2	14.3	15.4	15.4	15.2	17.3	16.7	18.6	16.0	16.1	16.8	16.4	1.6	.4
29	19.2	18.0	14.4	14.8	15.7	15.5	15.5	17.5	17.2	19.1	16.2	16.3	17.0	16.6	1.5	.4
+ 1	19.0	18.2	14.4	14.8	15.6	15.5	15.4	17.5	17.2	19.0	16.0	16.1	16.8	16.6	1.5	.4
+ 2	18.9	17.6	14.4	14.8	15.5	15.5	15.4	17.5	17.0	18.1	16.0	16.0	16.7	16.4	1.3	.4
+ 3		17.8	14.4	14.6	15.4	15.6	15.1	17.3	17.0	17.9	16.0	16.1	16.6	16.2	1.2	.3
+30	18.0	17.0	13.8	14.0	15.1	15.0		17.1	16.3	16.3	15.4	15.2	15.4	15.7	1.3	.4
+60					14.8	14.8	14.3	16.7	15.3	15.9	15.5	15.2	15.6	15.3	.7	.2

TABLE 4

SUB MAXIMAL EXERCISE

Ambient Temp. 24°C

Time (min.)	Hct	Hb	PV_{Hct}	PV_{Hb}	Na_{cn}	Na_{co}	Cl_{cn}	Cl_{co}	Ca_{cn}	Ca_{co}	$Prot_{cn}$	$Prot_{co}$	K_{cn}	K_{co}	Osm_{cn}	Osm_{co}
	%Δ	gr%	%Δ	%Δ	mEq/L	%Δ	mEq/L	%Δ	mEq/L	%Δ	gr%	%Δ	mEq/L	%Δ	mOsm/L	%Δ
- 5	37.5	14.6			144.6		108.8		4.83		7.00		3.8		298.2	
10	39.7	15.7	-8.9	-10.3	147.4	-8.5	110.1	-9.2	5.07	-5.8	7.60	-2.6	4.5	+ 7.1	305.4	-8.1
29	39.8	15.8	-9.2	-11.0	147.1	-9.4	110.3	-9.7	5.11	-5.9	7.64	-2.8	4.7	+ 9.3	304.9	-9.0
+ 1	39.6	15.6	-8.5	- 9.6	147.7	-7.6	110.4	-8.2	5.10	-4.5	7.60	-1.8	4.5	+ 7.1	305.1	-7.4
+ 2	39.4	15.5	-7.7	- 8.7	146.1	-7.7	109.6	-8.0	5.03	-4.9	7.49	-2.2	4.3	+ 2.4	307.6	-5.8
+ 3	39.0	15.3	-6.1	- 6.9	145.6	-6.2										
+30	37.7	14.7	- .8	- 1.0	145.5	- .3	108.2	-1.5	4.86	- .4	7.06	- .1	4.2	+10.5	300.2	- .3
+60	37.3	14.6	+ .8	+ .3	145.3	+ .8	108.0	- .4	4.87	+1.2	7.03	+ .7	4.3	+13.2	301.1	+1.3
Ambient Temp. 40°C																
- 5	38.0	14.9			142.5		107.3		4.90		7.39		3.9		298.3	
10	39.8	15.7	-7.3	- 7.9	145.2	-6.1	109.3	-6.1	5.22	-1.9	7.89	-1.6	4.5	+ 7.1	306.3	-5.3
29	40.2	15.9	-8.8	- 9.6	144.9	-8.1	109.3	-7.9	5.32	-1.8	8.05	-1.5	4.6	+ 7.0	306.1	-7.2
+ 1	39.9	15.9	-7.7	- 9.2	144.7	-7.7	111.2	-5.8	5.28	-2.0	8.06	- .9	4.5	+ 4.7	305.5	-6.9
+ 2	40.0	15.8	-8.1	- 8.8	143.6	-8.0	109.6	-6.8	5.12	-4.7	7.97	-1.6	4.3	0.0	304.4	-6.9
+ 3	39.8	15.7	-7.3	- 7.9	143.5	-7.2										
+30	38.7	15.1	-2.9	- 2.5	144.0	-1.4	108.6	-1.3	4.94	-1.6	7.59	+ .3	4.2	+ 5.0	302.4	-1.1
+60	38.2	15.0	- .8	- 1.0	144.7	+ .6			5.02	+1.4	7.47	+ .1	4.2	+ 7.7	304.7	+1.1

TABLE 5

MVC (μ^3)

Ambient Temp. 24°C

Subj.	TI	TI	RE	RE	CL	CL	CL	FU	FU	FU	RO	RO	RO	$\bar{X}$	SD	±SE
% Max $\dot{V}_{O_2}$	57%	65%	41%	60%	40%	55%	58%	44%	57%	74%	52%	60%	75%	56%	10	3
Time (min.)																
-30	86.0	89.8	79.6	81.0	84.0	85.6	84.0	79.3	80.8	81.3	84.5	83.3	84.0	83.3	2.9	.80
- 5	85.9	89.8	79.7	81.0	84.0	85.6	83.5	79.8	80.7	81.5	84.3	83.0	83.5	83.3	2.9	.80
- 5	86.5	90.2	79.3	81.3	83.6	86.1	84.4	79.3	81.4	81.7	85.9	84.9	84.4	83.8	3.1	.86
- 5	86.8	89.0	79.6	81.1	83.9	85.4	84.9	80.1	80.0	80.9	84.1	84.6	83.9	83.4	2.8	.77
10	85.2	88.2	79.2	79.4	82.8	85.7	83.8	80.1	81.7	81.4	83.8	82.4	83.2	82.8	2.6	.72
29	85.8	89.6	76.9	78.6	82.5	85.5	83.6	79.4	80.1	81.6	83.3	82.0	82.0	82.3	3.3	.91
+ 1	85.2	90.4	77.8	79.8	82.7	85.4	83.7	79.1	81.0	82.9	84.8	83.0	83.1	83.0	3.3	.91
+ 2	85.7	89.8	78.2	79.6	82.3	85.2	83.0	79.5	80.7	82.4	83.6	83.3	83.5	82.8	3.0	.83
+ 3	85.9	89.9	79.6	80.5	81.3	85.1	83.7	79.9	80.5	81.6	83.4	83.5	83.8	82.9	2.9	.80
+30	86.2	88.3	78.0	80.1	82.9	85.3	84.2	79.4	81.2	80.0	83.5	83.5	83.8	82.8	2.9	.80
+60	85.7	88.9	79.4	79.6	83.5	85.4	83.6	80.1	81.5	81.1	84.6	83.8	84.5	83.2	2.7	.75
							OSMOLARITY (mOsm/L)									
-30	304.2	299.0	299.8	301.5	303.5	289.8	300.0	301.0	304.4	306.8	298.1	300.3	303.2	300.8	4.1	1.10
- 5	304.2	299.7	299.8	301.5	303.5	289.8	299.6	301.0	304.4	306.8	298.1	300.3	303.2	300.6	4.1	1.10
- 5																
- 5	304.2	293.9	297.8	298.8	303.5	287.8	299.6	301.0	304.4	303.6	292.0	300.3	299.4	298.8	5.0	1.40
10	313.8	307.1	299.8	307.1	310.8	293.9	308.2	307.8	309.3	319.8	299.2	305.7	310.6	307.2	6.6	1.80
29	307.4	308.5	301.6	310.9	308.4	289.2	305.2	306.6	309.6	319.8	299.2	309.0	313.5	306.8	7.3	2.00
+ 1	308.0	311.3	300.4	313.0	313.0	285.6	309.2	310.6	311.0	314.9	304.6	307.0	311.5	305.6	5.8	1.60
+ 2	307.1	302.7	299.2	304.5	310.0	294.0	306.1	305.2	308.8	314.9	297.8	308.6	305.0	304.9	5.5	1.50
+ 3																
+30	302.1	298.2	302.2	300.9	305.6	291.5	308.6	306.0	306.2	314.2	297.8	306.2	303.1	303.2	5.6	1.60
+60	299.0	298.2	300.0	299.5	304.3	291.5	309.9	306.8	306.8	303.9	298.2	306.2	303.1	302.1	5.0	1.40

TABLE 6

MCV (μ^3)

Ambient Temp. 40°C

Subj.	TI	TI	RE	RE	CL	CL	CL	FU	FU	FU	RO	RO	RO	$\bar{X}$	SD	$\pm\frac{SE}{3}$
% Max $\dot{V}_{O_2}$	53%	56%	41%	60%	41%	55%	60%	38%	62%	74%	52%	60%	73%	56	10	3
Time (min.)																
-30	88.6	87.1	79.2	80.9	85.5	85.0	82.9	79.8	80.5	80.4	85.3	85.6	83.3	83.1	2.5	.69
- 5	88.6	87.1	79.2	80.9	84.8	85.0	84.0	81.0	79.5	78.6	85.0	84.6	83.1	83.1	3.2	.88
- 5	89.4	87.8	79.2	80.9	85.4	85.0	84.2	81.0	81.3	78.8	86.2	85.2	84.0	83.7	3.3	.91
- 5	87.7	87.3	78.4	81.2	84.2	85.4	83.1	81.5	80.8	79.6	84.3	84.5	83.3	83.2	2.8	.77
10	87.5	87.9	78.0	79.6	83.9	83.6	83.3	80.8	80.6	78.2	84.6	84.4	82.1	82.6	3.2	.88
29	88.5	87.7	78.7	78.5	84.6	84.6	82.8	80.9	80.6	79.0	83.6	84.0	82.9	82.8	3.2	.88
+ 1	87.4	86.8	78.6	78.2	83.6	83.3	83.3	80.6	79.7	79.5	84.1	83.8	83.0	82.4	2.9	.80
+ 2	88.0	86.1	78.9	79.3	83.7	83.3	82.4	80.6	80.5	79.7	83.3	84.1	82.5	82.4	2.7	.75
+ 3	87.5	86.1	78.9	79.2	83.9	83.9	83.0	79.9	80.1	80.1	83.3	83.6	82.2	82.4	2.6	.72
+30	87.0	87.4	79.2	78.9		84.4	83.0	80.4	80.9	78.0	84.8	85.0	83.0	82.7	3.0	.82
+60	87.4	87.2	79.0	79.1	83.8	83.2	83.8	82.2	81.5	78.1	85.3	85.6	83.2	82.9	2.2	.61
								OSMOLARITY (mOsm/L)								
-30	305.4	301.5	300.2	295.0	303.4	299.1	304.1	319.0	309.3	306.7	306.1	301.9	298.0	306.2	6.0	1.60
- 5	310.1	301.5	301.6	296.8	294.1	304.3	307.5	313.6	309.6	303.6	299.4	303.0	299.3	303.4	5.6	1.50
- 5																
- 5	304.4	301.5	299.7	293.0	294.6	292.6	300.7	313.6	309.6	307.5	302.0	301.8	296.3	301.3	6.3	1.80
10	312.5	308.9	304.3	302.1	303.5	303.2	311.6	332.3	315.5	313.0	311.7	305.9	305.3	310.0	7.9	2.20
29	316.9	309.0	304.3	309.0	300.7	308.7	307.1	315.7	318.2	320.4	304.6	308.3	303.0	309.6	6.2	1.70
+ 1	311.4	310.2	302.6	305.3	299.0	307.1	309.5	326.0	315.6	317.0	303.8	308.3	304.1	309.2	7.1	2.00
+ 2	302.6	306.4	302.6	303.6	304.0	300.3	304.0	320.2	313.0	313.6	309.8	304.5	297.5	306.3	6.2	1.70
+ 3																
+30	309.3	304.4	303.4	300.0	299.3	299.6	312.2	316.1	319.3	310.7	301.7	302.3	300.9	306.1	6.7	1.90
+60	306.0	305.8	302.0	301.0	301.0	307.2	319.4	314.1	312.8	292.0	303.6	303.4	303.9	306.3	8.1	2.20

TABLE 7

SUB MAXIMAL EXERCISE

Ambient Temp. 24°C; < 55% max $\dot{V}_{O_2}$

TIME	pH		pCO_2		pO_2	
min.	$\bar{X}$	±SE	$\bar{X}$	±SE	$\bar{X}$	±SE
- 5	7.348	0	48.2	3.9	37.5	6.4
- 5	7.349	0	49.8	4.3	37.4	5.7
10	7.336	0	47.7	3.5	40.3	5.3
29	7.359	0	45.7	3.5	52.2	7.3
+ 1	7.357	0	42.7	4.1	62.9	11.1
+ 2	7.360	0	43.0	3.1	61.0	6.1
+ 3	7.352	0	43.6	3.7	54.7	7.6
+30	7.358	0	50.9	2.2	32.5	3.1
+60	7.347	0	52.6	2.0	24.7	1.9
Ambient Temp. 24°C; > 55% max $\dot{V}_{O_2}$						
- 5	7.346	0	52.1	2.6	32.1	4.0
- 5	7.344	0	48.4	3.2	36.7	3.6
10	7.313	0	48.9	1.8	49.2	6.0
29	7.327	0	40.5	1.7	57.0	4.0
+ 1	7.296	0	40.1	2.2	57.0	5.7
+ 2	7.304	0	39.9	1.9	56.2	6.0
+ 3	7.309	0	39.5	2.3	58.9	9.0
+30	7.353	0	49.7	1.8	30.3	1.9
+60	7.356	0	50.2	2.5	28.6	3.7
Ambient Temp. 40°C; < 55% max $\dot{V}_{O_2}$						
- 5	7.368	0	44.5	2.0	46.7	3.8
- 5	7.369	0	43.0	1.6	50.3	5.2
10	7.361	0	43.9	1.9	54.1	5.4
29	7.371	0	41.1	1.6	60.6	6.5
+ 1	7.380	0	37.6	3.1	72.9	4.8
+ 2	7.385	0	36.9	2.7	73.4	5.3
+ 3	7.387	0	38.4	3.1	70.1	6.4
+30	7.372	0	45.0	3.2	40.8	4.2
+60	7.378	0	46.7	2.2	48.3	1.5
Ambient Temp. 40°C; > 55% max $\dot{V}_{O_2}$						
- 5	7.373	0	46.1	1.4	48.2	5.9
- 5	7.372	0	46.6	1.7	51.2	7.3
10	7.354	0	43.3	2.0	56.2	4.6
29	7.376	0	37.9	1.8	60.3	4.5
+ 1	7.351	0	39.9	2.2	64.1	9.1
+ 2	7.350	0	38.8	1.7	64.0	8.1
+ 3	7.357	0	39.4	1.3	64.1	4.1
+30	7.382	0	43.9	1.4	50.4	4.1
+60	7.369	0	50.9	1.9	40.5	7.2

TABLE 8

MEAN ARTERIAL BLOOD PRESSURE (mm Hg)

Subj.	TR	AR	PS	CS	JC	CL	JD	Mean	SD	SE
Time (min.)										
0	122	100	103	125	113	138	106	115	13.7	5.0
3	138	102	127	123	116	139	122	123	12.8	4.9
6	132	97	136	137	146	162	123	133	20.1	7.7
9	131	97	147	149	146	166	125	137	22.1	8.5
12	132	102	143	147	155	158	137	139	18.7	7.1
15	136	94	149	148	142	159	133	137	20.9	8.0
R	130	94	115	129	126	120	124	120	12.4	4.9

HEMATOCRIT (%)

0	43.8	41.2	42.8	43.2	40.2	40.3	43.2	42.1	1.5	.6
3	44.9	42.0	44.6	43.9	41.0	41.0	45.2	42.8	1.6	.6
6	44.9	42.1	45.9	42.2	41.0	42.9	46.2	43.6	2.0	.8
9	44.2	42.2	45.9	43.8	42.0	44.1	47.0	44.2	1.8	.7
12	44.2	42.1	45.9	44.3	43.0	44.4	47.2	44.4	1.7	.7
15	45.1	42.7	45.9	45.8	43.8	45.2	47.4	45.1	1.5	.6
R	46.0	43.0	45.9	46.0	44.0	45.3	47.4	45.3	1.5	.6

OXYGEN CONSUMPTION (ml/min/Kg)

0	4.4	3.2	4.4	3.0	4.3	3.4	3.5	3.7	.6	.2
3	15.3	13.6	20.2	13.8	10.3	8.1	9.4	12.9	4.1	1.5
6	17.6	14.7	26.2	17.5	15.9	20.2	11.3	17.6	4.6	1.8
9	18.9	18.3	36.0	23.4	23.6	25.1	15.7	23.0	6.6	2.5
12	23.4	20.5	38.6	31.9	28.7	30.1	20.8	27.7	6.6	2.5
15	27.4	24.5	48.5	36.6	38.6	34.9	24.5	33.5	8.7	3.3

TABLE 9

ISOMETRIC EXERCISE

	Hct	pH	pCO_2	pO_2	Na	K	Ca	Osm	RBC	Hb	MCV
	%		mm Hg	mm Hg	mEq/L	mEq/L	mEq/L	mOsm/L	$10^6/mm^3$	mg%	μ^3
Right Handgrip											
Pre	43.4	7.30	58.4	36.6	140.4	3.7	4.82	301.9			
Pre	43.4	7.30	56.5	37.2	140.0	3.7	4.80	301.6			
Ex.	44.6	7.21	63.6	34.1	142.4	4.6	5.13	307.8			
Ex.	44.7	7.09	93.6	48.7	147.6	4.7	5.21	322.8			
+1	44.6	7.17	63.2	59.0	141.6	3.5	4.82	308.0			
+2	43.8	7.25	52.1	54.3	138.5	3.4	4.75	301.2			
Left Hand Control											
Pre	43.1	7.30	58.5	31.6	140.4	3.7	4.78	303.3			
Pre	43.1	7.30	55.0	29.3	140.4	3.7	4.75	302.6			
Ex.	43.1	7.31	50.2	38.8	139.9	3.6	4.81	301.0			
Ex.	43.1	7.32	53.6	47.5	139.8	3.6	4.75	300.7			
+1	43.0	7.31	50.9	39.6	141.0	3.6	4.72	300.3			
+2	43.0	7.30	53.4	35.4	139.8	3.6	4.75	300.4			
ISOTONIC EXERCISE											
Right Hand-squeezing											
Pre	40.8	7.31	52.8	43.3	139.0	4.0	4.63	296.0	4.81	14.8	84.7
Pre	40.8	7.31	53.0	43.3	139.0	4.0	4.63	296.0	4.78	14.8	84.8
Ex.	42.3	7.13	85.5	45.0	145.8	4.6	4.97	314.6	5.04	15.2	84.0
Ex.	42.1	7.18	69.1	56.8	142.5	4.4	4.82	304.7	4.96	15.2	85.0
+1	41.8	7.21	56.2	58.6	140.4	3.8	4.74	297.6	4.92	14.9	85.6
+2	41.7	7.23	56.0	58.6	139.7	3.8	4.71	297.1	4.82	14.8	86.4
Left Hand Control											
Pre	40.8	7.30	54.8	29.7	138.8	4.1	4.69	297.0	4.78	14.8	84.9
Pre	40.8	7.30	56.2	32.4	138.8	4.1	4.69	297.0	4.82	14.6	84.4
Ex.	40.9	7.30	53.0	40.0	138.1	4.0	4.71	299.6	4.84	14.8	84.9
Ex.	40.9	7.32	53.0	36.0	138.7	4.0	4.69	297.2	4.81	14.8	85.8
+1	40.9	7.32	47.1	42.7	138.6	4.0	4.74	297.3	4.79	14.5	84.5
+2	40.9	7.33	47.9	47.0	138.4	4.0	4.73	296.4	4.81	14.6	85.0

TABLE 10

DEHYDRATION (2.5%)

Ambient Temp. 58°C

	Hct	Hb	PV_{Hct}	PV_{Hb}	Na_{cn}	Na_{co}	Cl_{cn}	Cl_{co}	Ca_{cn}	Ca_{co}	$Prot_{cn}$	$Prot_{co}$	K_{cn}	K_{co}	Osm_{cn}	Osm_{co}
	%	gr%	%Δ	%Δ	mEq/L	%Δ	mEq/L	%Δ	mEq/L	%Δ	gr%	%Δ	mEq/L	%Δ	mOsm/L	%Δ
Time (min.)																
- 5	37.3	14.7			144.9		109.3		5.00		7.46		3.9		296.0	
25	36.7	14.7	+2.6	+1.0	145.0	+1.0	111.3	+2.8	5.20	+5.0	7.13	-3.5	4.1	+5.1	297.5	+1.5
25	36.7	14.9	+2.6	- .4	146.8	+ .9	112.0	+2.1	5.28	+5.2	7.20	-3.9	4.1	+5.1	297.5	+ .1
60	37.6	15.1	-1.3	-3.1	146.6	-2.0	112.8	0.0	5.41	+4.8	7.56	-1.8	4.2	+5.0	300.5	-1.6
60	37.6	15.1	-1.3	-3.1	146.6	-2.0	112.5	~ .3	5.34	+3.5	7.48	-2.9	4.2	+5.0	300.5	-1.6
135	38.7	15.8	-5.8	-9.0	147.3	-7.5	113.0	~5.9	5.23	-4.9	7.80	-4.9	4.3	0.0	301.3	-7.4
135	38.9	15.7	-6.6	-8.8	147.4	-7.2	113.3	~5.4	5.25	-4.2	7.82	-4.4	4.3	0.0	302.0	-6.9
+ 20	38.6	15.5	-5.4	-7.1	147.1	-5.7	112.8	~4.2	4.99	-7.2	7.67	-4.5	4.0	-4.8	303.0	-4.9
+ 20	38.6	15.5	-5.4	-7.1	147.0	-5.7	113.3	~4.2	5.00	-7.1	7.59	-5.5	4.0	-4.8	303.0	-4.9

TABLE 11

	SUBMAXIMAL EXERCISE				MAXIMAL EXERCISE						DEHYDRATION		
	24°C		40°C		Non-Ath		Ath (UT)		Ath (T)			58.5°C	
TIME min.	MCV	±SE	MCV	±SE	MCV	±SE	MCV	±SE	MCV	±SE	TIME min.	MCV	±SE
- 5	83.3	.7	83.1	.7	82.6	2.0	85.3	.8	86.8	.4	- 5	83.6	2.3
- 5	83.4	.7	83.2	.7	82.9	1.9	85.3	.8	86.8	.4	- 5	83.6	1.8
10	82.8	.7	82.6	.9							25	82.8	2.4
29	82.3	.9	82.8	.9							25	82.0	2.2
+ 1	83.0	.9	82.4	.8	83.2	1.4	85.8	1.0	86.0	.7	60	82.3	2.1
+ 2	82.8	.8	82.4	.7	83.5	1.4	86.5	1.0	86.6	.8	60	82.6	2.4
+ 3	82.9	.8	82.4	.7	83.6	1.7	86.3	.8	87.0	.9	135	82.2	2.3
+30	82.8	.8	82.7	.8	82.8	1.4	85.8	.9	85.7	.6	135	82.3	2.1
+60	83.2	.7	82.9	.6							+ 20	82.5	2.1
	Osm		Osm		Osm		Osm		Osm			Osm	
- 5	300.6	1.1	303.4	1.6	297.5	2.4	294.6	1.1	292.6	.6	- 5	296.0	2.5
- 5	298.8	1.4	301.3	1.8	297.5	2.4	295.4	1.6	292.9	.5	- 5		
10	307.2	1.8	310.0	2.2							25	297.5	3.6
29	306.8	2.0	309.6	1.7							25	297.5	1.8
+ 1	305.6	1.6	309.2	2.0	329.5	7.5	315.7	2.8	307.5	1.5	60	300.5	2.0
+ 2	304.9	1.5	306.3	1.7	323.5	2.5	310.7	2.8	309.4	1.0	60	300.5	2.6
+ 3					318.7	1.5	307.5	3.0	301.7	2.5	135	301.3	2.7
+30	303.2	1.6	306.1	1.9	310.0	4.1	299.4	1.9	296.2	.9	135	302.0	2.9
+60	302.1	1.4	306.3	2.2							+ 20	303.0	2.6

UT = Untrained
T = Trained
Ath = Athletes

TABLE 12

DEHYDRATION

TIME	pH		pCO_2		pO_2	
min.	$\bar{X}$	±SE	$\bar{X}$	±SE	$\bar{X}$	±SE
- 5	7.344	0	43.8	1.3	45.5	7.5
- 5	7.362	0	42.8	2.9	49.1	6.7
25	7.394	0	41.1	1.5	58.5	7.3
25	7.401	0	37.6	1.4	66.5	5.6
60	7.406	0	37.8	1.9	67.3	3.3
60	7.402	0	37.4	1.9	79.9	3.5
120	7.439	0	33.5	2.0	70.2	4.6
120	7.436	0	32.4	1.6	76.2	4.1
120	7.426	0	34.5	1.7	76.6	3.2
+20	7.391	0	39.1	1.1	58.5	2.7
+20	7.385	0	37.7	2.0	63.1	4.6
			NON-HEAT ACCLIMATIZED			
- 5	7.342	0	49.5	1.5	34.4	6.2
- 5	7.341	0	45.1	2.4	38.5	7.2
60	7.385	0	42.9	1.7	50.6	8.0
60	7.391	0	37.7	3.6	59.1	12.9
+ 5	7.417	0	33.0	.6	64.7	8.1
+30	7.391	0	38.8	3.2	56.0	9.4
+31	7.394	0	36.2	2.5	67.5	10.6
+32	7.387	0	39.2	1.9	64.1	11.0
			HEAT ACCLIMATIZED			
- 5	7.334	0	51.8	2.2	38.0	5.5
- 5	7.331	0	49.5	2.3	38.8	4.8
60	7.373	0	44.3	1.6	53.4	7.3
60	7.381	0	37.9	1.9	54.4	8.2
+ 5	7.392	0	35.5	2.7	71.2	5.9
+30	7.373	0	40.1	3.8	53.6	7.0
+31	7.388	0	37.8	2.6	70.1	9.5
+32	7.390	0	37.6	2.4	74.6	7.6

TABLE 13

TIME	MAX $\dot{V}_{O2}$		Lactate		pH		RBC		Hb		Hct		MCV		Osm	
min.	ml/min/Kg		mg%				x $10^6/mm^3$		mg%		%		μ^3		mOsm/L	
	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
- 5			11.9 (1.5)	13.0 (1.2)	7.33	7.34	4.92 (.1)	4.75 (.1)	15.1 (.2)	14.5 (.2)	43.4 (.7)	42.8 (.7)	85.3 (.8)	86.8 (.4)	295.4 (1.6)	292.9 (.5)
	59.3 (2.2)	62.1 (1.8)														
+ 2			107.7 (8.8)	98.1 (8.2)	7.05	7.14	5.45 (.1)	5.30 (.1)	16.7 (.2)	16.3 (.2)	48.3 (.7)	47.5 (.8)	85.8 (1.0)	86.0 (.7)	315.7 (2.8)	307.5 (1.5)
+ 3			101.6 (8.7)	99.4 (7.5)	7.09	7.17	5.35 (.1)	5.24 (.1)	16.5 (.2)	16.1 (.2)	47.9 (.8)	47.4 (.8)	86.5 (1.0)	86.6 (.8)	310.7 (2.8)	309.0 (1.0)
+ 4					7.14	7.15	5.34 (.1)	5.18 (.1)	16.3 (.2)	16.0 (.2)	47.8 (.9)	47.0 (.8)	86.3 (1.0)	87.0 (.9)	307.5 (3.0)	301.7 (2.5)
+25			59.0 (8.3)	40.4 (3.9)	7.27	7.33	5.05 (.1)	4.90 (.1)	15.5 (.4)	15.0 (.2)	44.9 (.9)	43.9 (.9)	85.8 (1.0)	85.7 (.6)	299.4 (1.9)	296.2 (.9)

TABLE 14

MAXIMAL EXERCISE (ATH) - Pre-Training (N=12)

TIME	Hct	Hb	PV_{Hct}	PV_{Hb}	Na_{cn}	Na_{co}	Cl_{cn}	Cl_{co}	Ca_{cn}	Ca_{co}	$Prot_{cn}$	$Prot_{co}$	K_{cn}	K_{co}	Osm_{cn}	Osm_{co}
min.	%	gr%	%Δ	%Δ	mEq/L	%Δ	mEq/L	%Δ	mEq/L	%Δ	gr%	%Δ	mEq/L	%Δ	mOsm/L	%Δ
- 5	38.5	15.2			143.1		105.3		4.71		7.42		3.9		294.8	
+ 2	42.7	16.8	-16.0	-15.7	147.3	-13.2	106.5	-14.7	5.20	- 7.0	8.36	-5.0	4.5	- 2.2	313.4	-10.4
+ 3	42.5	16.7	-15.3	-14.9	146.5	-12.8	107.3	-13.3	5.06	- 8.5	8.27	-5.2	3.7	-19.6	309.6	- 9.9
+ 4	42.3	16.5	-14.6	-13.6	145.9	-11.9	106.5	-12.6	4.97	- 8.8	8.20	-4.5	3.5	-22.2	307.5	- 9.9
+25	39.4	15.8	- 3.7	- 5.2	144.0	- 4.6	105.0	- 5.5	4.85	- 2.4	7.63	-2.5	4.2	+ 2.4	298.6	- 4.0
MAXIMAL EXERCISE (ATH) - Pre-Training (N=7)																
- 5	38.2	15.1			142.9		105.1		4.74		7.40		3.9		295.4	
+ 2	42.5	16.7	-16.4	-15.9	147.8	-13.0	106.4	-14.8	5.23	- 7.2	8.48	-3.6	4.5	- 2.9	315.7	-10.1
+ 3	42.1	16.5	-15.0	-14.3	146.6	-12.0	107.3	-12.5	5.04	- 8.8	8.26	-4.3	3.8	-16.5	310.7	- 9.8
+ 4	42.0	16.3	-14.6	-13.1	146.2	-11.1	106.7	-11.7	4.98	- 8.7	8.29	-2.6	3.5	-22.0	307.5	- 9.5
+25	39.5	15.5	- 5.3	- 4.6	143.8	- 4.0	104.6	- 5.1	4.83	- 2.8	7.71	- .6	4.2	+ 2.7	299.4	- 3.3
MAXIMAL EXERCISE (ATH) - Post-Training (N=7)																
- 5	37.5	14.5			140.9		103.3		4.58		6.81		4.0		292.9	
+ 2	41.5	16.3	-15.4	-16.7	145.9	-13.8	105.7	-14.8	5.07	- 7.8	7.86	-3.9	4.7	- 2.1	307.5	-12.6
+ 3	41.4	16.1	-15.1	-15.6	145.6	-12.7	106.8	-12.7	5.02	- 7.4	7.83	-2.9	3.9	-17.0	309.0	-10.9
+ 4	41.1	16.0	-14.0	-14.6	143.5	-13.0	104.4	-13.6	4.81	-10.3	7.66	-3.9	3.7	-21.3	301.7	-12.0
+25	38.3	15.0	- 3.3	- 4.6	142.5	- 3.5	104.1	- 3.9	4.72	- 1.7	7.12	- .2	4.3	+ 2.4	296.2	- 3.5
MAXIMAL EXERCISE (NON-ATH) (N=4)																
- 5	38.7	15.2			142.8		105.6		4.84		7.54		3.8		297.5	
+ 2	43.1	17.1	-16.6	-17.5	152.9	-11.7	111.3	-13.0	5.09	-13.3	8.86	-3.1	5.1	+10.9	329.5	- 8.6
+ 3	42.6	17.0	-15.0	-16.3	151.8	-11.0	110.3	-12.5	5.15	-10.9	8.68	-3.7	4.1	- 8.9	323.5	- 9.0
+ 4	42.6	16.8	-15.0	-15.3	148.5	-11.9	108.3	-13.2	5.15	- 9.8	8.68	-2.5	3.6	-20.0	318.7	- 9.0
+25	40.2	15.9	- 6.0	- 6.7	140.2	- 8.4	106.0	- 6.4	4.88	- 6.0	8.26	+2.1	3.9	- 4.9	310.0	- 2.3

TABLE 15

MAXIMAL EXERCISE

TIME	UNTRAINED (ATH.)					TRAINED (ATH.)					UNTRAINED (NON-ATH.)				
min.	pH	pCO_2	pO_2	HCO_3	Lact.	pH	pCO_2	pO_2	HCO_3	Lact.	pH	pCO_2	pO_2	HCO_3	Lact.
		mm Hg	mm Hg	mM/L	mg%		mm Hg	mm Hg	mM/L	mg%		mm Hg	mm Hg	mM/L	mg%
- 5	7.335	48.5	29.2	24.3		7.343	51.5	34.6	26.9		7.330	52.5	32.1	26.1	
±SE	0	1.7	2.0			0	2.0	3.5			0	.5	3.2		
- 5	7.334	46.2	33.4	23.0	11.9	7.343	44.5	37.8	23.0	13.0	7.336	47.7	34.8	24.0	8.8
±SE	0	1.9	2.2		1.5	0	1.5	4.5		1.2	0	1.0	3.4		.7
+ 1	7.046	65.1	38.9	17.0		7.143	60.5	44.0	19.5		7.049	76.2	31.9	18.0	135.2
±SE	0	4.9	4.1			0	7.2	5.6			.1	8.6	3.9		14.8
+ 2	7.090	44.7	61.1	13.0	107.7	7.174	43.6	60.7	15.2	98.1	7.100	52.0	56.3	15.8	128.0
±SE	0	3.9	6.3		8.8	0	2.6	7.5		8.2	.1	7.5	6.7		19.9
+ 3	7.144	35.3	65.9	11.6	101.6	7.154	44.8	57.6	15.2	99.4	7.113	44.9	56.1	14.0	121.0
±SE	0	2.5	8.4		8.7	0	4.5	7.3		7.5	0	4.6	7.7		9.3
+25	7.271	43.4	30.8	19.0	59.0	7.333	45.2	36.2	22.2	40.4	7.279	42.1	38.2	19.0	75.7
±SE	0	1.2	2.4		8.3	0	2.1	7.6		3.9	0	4.6	6.5		29.4

TABLE 16

	Hct .96		RBC		Hb		MCV		MCHC		Osm		Prot.		Na		K	
TIME	%		$10^6/mm^3$		gr%		μ^3		%		mOsm/L		gr%		mEq/L		mEq/L	
min.	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	HA
Cool																		
0	42.8	41.3	4.96	4.76	15.7	15.0	86.3	87.1	36.7	36.1	297.8	296.1	7.46	7.24	148.3	147.4	4.1	4.2
±SE	2.0	1.4	.2	.2	.7	.5	1.1	.8	.4	.5	2.7	2.2	.2	.2	1.3	1.6	.1	.1
0	42.8	41.3	4.97	4.76	15.8	14.9	86.2	87.1	36.9	36.1	297.7	295.4	7.48	7.20	148.6	147.7	4.1	4.2
±SE	1.9	1.4	.2	.2	.7	.5	1.2	.6	.3	.5	2.5	1.8	.3	.2	1.2	2.0	.1	.1
Heat-R																		
60	41.5	40.0	4.83	4.60	15.4	14.4	85.9	87.1	37.0	36.1	295.8	294.6	7.24	6.77	148.2	146.6	4.4	4.4
±SE	1.9	1.1	.1	.2	.7	.4	1.5	1.7	.3	.4	.9	1.5	.1	.1	1.2	.1	.1	.2
Heat-Ex																		
60	44.8	43.8	5.26	5.10	16.7	16.2	85.2	86.1	37.1	37.0	300.5	304.8	8.08	8.00	149.7	150.5	4.8	5.0
±SE	2.1	.9	.2	.1	.8	.4	1.5	1.1	.3	.5	1.6	1.3	.1	.0	2.0	.7	.1	.2
+ 5	45.7	43.8	5.35	5.12	16.8	16.3	85.2	85.7	36.8	37.2	299.9	302.4	8.13	8.02	150.5	150.9	4.7	4.8
±SE	2.7	1.0	.2	.2	.9	.4	1.8	1.2	.3	.6	1.4	1.8	.1	.1	1.9	1.2	.2	.2
+30	42.6	41.2	4.99	4.81	15.8	15.2	85.3	85.9	37.1	36.8	297.8	300.2	7.39	7.32	149.7	151.6	4.3	4.5
±SE	1.9	1.5	.2	.2	.9	.5	.7	1.3	.7	.6	.9	1.7	.1	.1	1.5	.7	.1	.1
+31	42.6	41.2	5.00	4.79	15.9	15.1	85.2	86.4	37.1	36.7	298.0	299.8	7.38	7.31	149.8	151.5	4.3	4.5
±SE	1.9	1.5	.2	.2	.8	.5	.6	1.2	.7	.6	1.0	1.2	.1	.1	1.4	.5	.1	.1

N-HA = Non-Heat Acclimatized
HA = Heat Acclimatized
Heat-R = Heat-Rest
Heat-Ex = Heat-Exercise

TABLE 17

	Hct		Hb		PV		Osm (mOsm/L)				Prot (gr%)				Na (mEq/L)			
TIME	%		gr%		%Δ		Cn	%Δ	Cn	%Δ	Cn	%Δ	Cn	%Δ	Cn	%Δ	Cn	%Δ
min.	N-HA	HA	N-HA	HA	N-HA	HA	N-HA	N-HA	HA	HA	N-HA	N-HA	HA	HA	N-HA	N-HA	HA	HA
Cool 0	38.9	37.6	15.8	14.9			297.7		295.4		7.48		7.20		148.6		147.7	
Heat-R 60	37.8	36.4	15.4	14.4	+ 4.5	+ 5.5	295.8	+ 2.4	294.6	+5.2	7.24	- .2	6.77	- .8	148.2	+ 2.8	146.6	+ 4.7
Heat-Ex 60	40.8	39.9	16.7	16.2	- 8.3	-11.4	300.5	- 8.7	304.8	-8.6	8.08	-2.3	8.00	-1.6	149.7	- 8.9	150.5	- 9.7
+ 5	41.6	39.9	16.8	16.3	-10.1	-11.9	299.9	-10.6	302.4	-9.9	8.13	-3.6	8.02	-1.9	150.5	-10.1	150.9	-10.1
+30	38.8	37.5	15.8	15.2	+ .2	- 1.8	297.8	- 1.1	300.2	- .2	7.39	-2.3	7.32	- .2	149.7	- .4	151.6	+ .8
+60	38.8	37.5	15.9	15.1	- .5	- 1.1	298.0	- 1.7	299.8	+ .3	7.38	-3.1	7.31	+ .3	149.8	- 1.0	151.5	+ 1.4
%Δ Pre(N-HA) - Post(HA)					+ 8.4			+ 7.5				+4.3				+ 7.6		

N-HA = Non-Heat Acclimatized
HA = Heat Acclimatized
Heat-R = Heat-Rest
Heat-Ex = Heat-Exercise

Table 18

Subj.	A	B	C	D	E	F	G	H	I	J	K	L	M	
2/Pre-ex Control 1	540	287	229	214	217	207	250	289	181	73	87	50	50	$\bar{X}$=206±36
3/Pre-ex Control 2	50	50	50	50	50	50	112	96	122	176	612	77	50	$\bar{X}$=118±43
4/Post-max (immediate)	50	88	90	500	220	476	477	477	402	452	460	460	486	$\bar{X}$=364±51
7/25 Rec.	580	298	344	384	297	329	411	–	500	121	394	700	464	$\bar{X}$=401±40

FIGURE 1

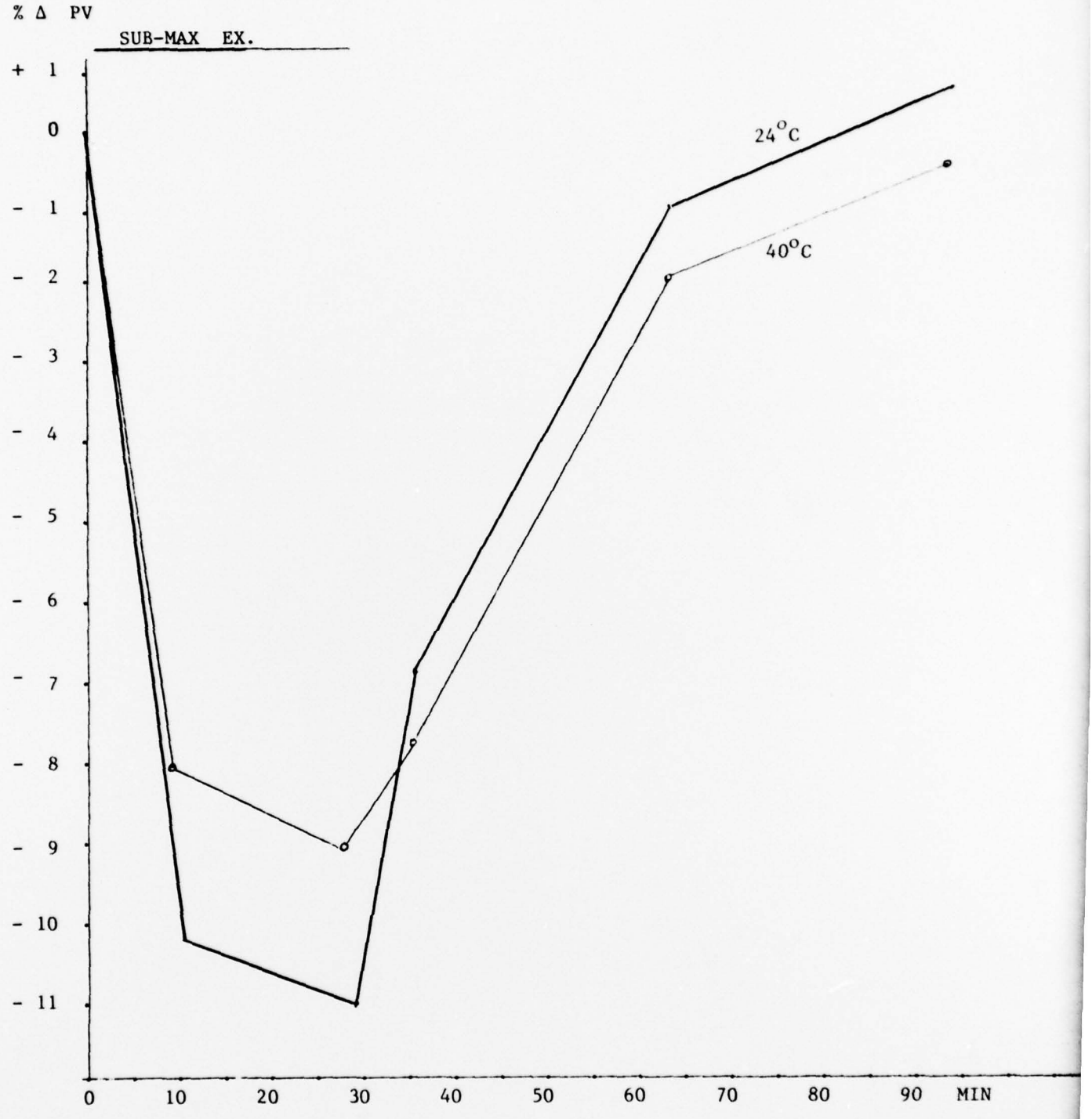
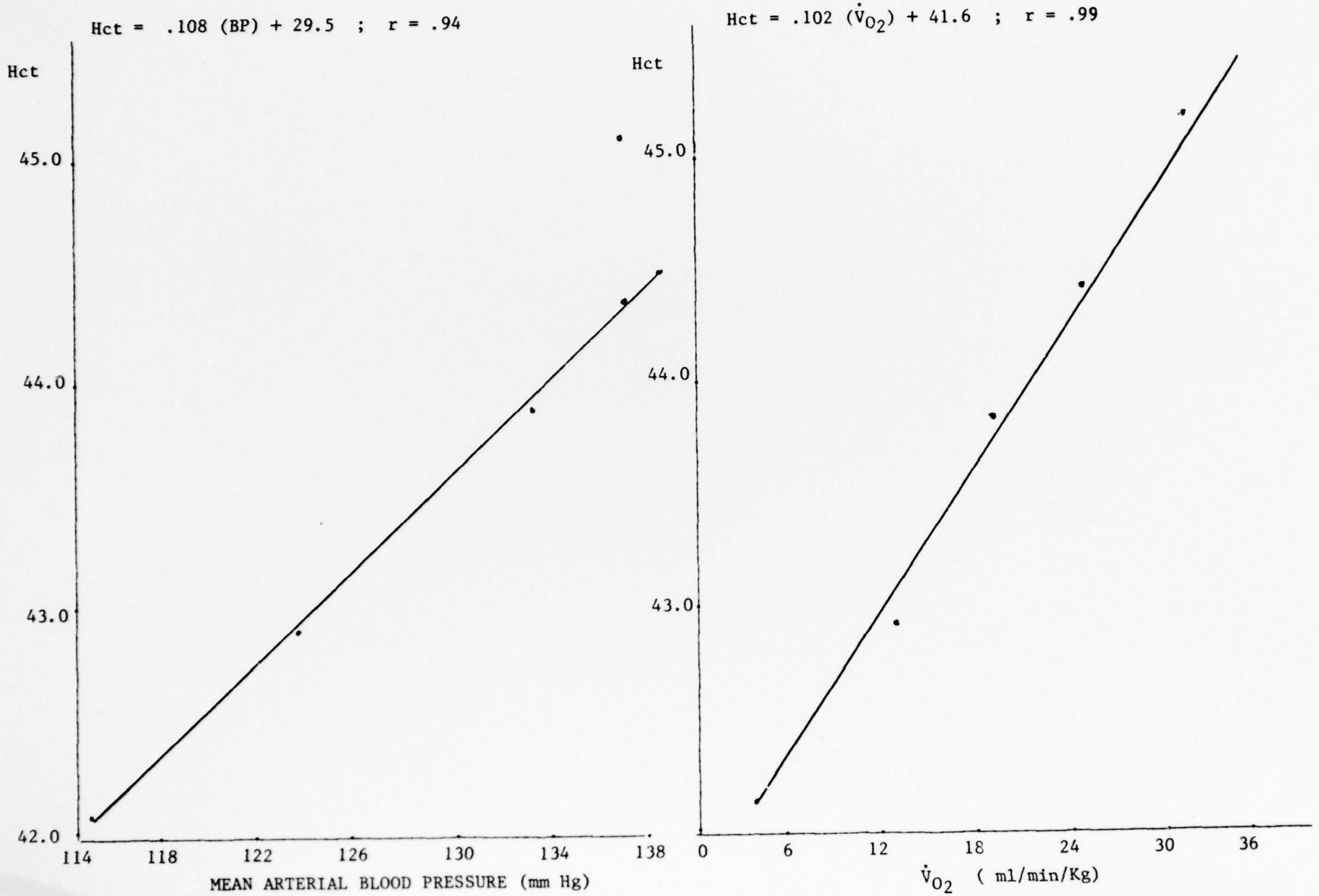

% Δ PV
SUB-MAX EX.
+ 1
0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
24°C
40°C
0
10
20
30
40
50
60
70
80
90
MIN

FIGURE 2

MEAN ARTERIAL BLOOD PRESSURE VS. HEMATOCRIT DURING INCREMENTAL EXERCISE



Changes in 13, 14 - dihydro - 15 - keto PGF_{2a} with Maximal Exercise